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Original article

The residual oil distribution regularity of low permeability oilfield

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ABSTRACT

Study on the residual oil distribution regularity is the important thing during the middle and later stage of the oilfield. With understanding and development of oilfield, the research methods of remaining oil are varied. Well block A is a low permeability oilfield and complex relationship between injection wells and production wells. The well pattern has low control of sand body. Based on the characteristics and the geological and dynamic data, technology of integrated 3-D geological modeling with reservoir numerical simulation is ensured to study the residual oil. Finally, deposition facies and flowing units are studied to analyze the residual oil distribution regularity. As a result, the types of residual oil were confirmed and the basis for the following development adjustment of the well block is provided.

1. Introduction

Low permeability reservoir field is vital to our country's oil & gas development. The residual oil of low permeability reservoir has varied distribution features in China such as tremendous quantity of gas & oil, various type of reservoirs and expansive distribution zone [1–3]. However, in the proven reservoir, low permeability oil reserves shows high rate of potentials to be developed. To ensure the remaining oil distribution is the key to the process of oilfield exploration, the only way to make rational development scheme [4,5]. Clarifying type and distribution of remaining oil is vital to enhance injection-production rate.

Based on present data, the main four methods to ensure the remaining oil distribution are geological method, reservoir simulation method, laboratory method and process engineering [6–8]. The key of reservoir simulation to analysis remaining oil lays in the establishment of reservoir model which takes anisotropy into consideration [9,10]. As a consequence, the reservoir model can reflect reservoir flow and development condition effectively. This article establishes the geologic model combined with deposition map and analysis remaining oil in low permeability reservoir mainly by numerical simulation. The integration of detailed geologic model and reservoir numeral simulation is realized.

2. Geologic modeling

Zone A mainly aims to develop target layer F with oil-bearing area 11.0 km^2, average efficient sickness 14.3 m, average porosity 13.5% and average air permeability 4.47 × 10^{-3} μm^2. Fault and lithology of the reservoir is compound. After many years of development, problems have been exposed such as low control of sands with present well pattern, defective injection-production system, ascend of moisture content and complex situation of sandstone drown out, water cut in the well ascending excessively fast and low efficient of inject water. The remaining oil distribution is the key to adjustment of development method. In order to adjust the well area, the methods to building detailed geologic model and reservoir numeral simulation have been used to clarify the type of remaining oil.

2.1. Fault characteristic

The reservoir type of A block is fault-lithology composite reservoir. This well block is a monocline structure plunged

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towards west by six normal faults which mainly strike near north-south or north-east. The whole well block is separated to A1 and A2 by an interconnecting complicate fault in the middle of the block. The distribution of fault is shown as Fig. 1.

2.2. Structure characteristic

Based on the fracture system and layering data of wells, girds are partitioned in computing module of structure model. As a result, grids in structure level can be generated.

Based on the principal that proper number of grids between wells, denser girds with tight wells and sparser girds with loose wells, together with the geological features, well distribution of the block and future adjustments, $148 \times 199 = 29\,452$ uneven corner-point grids are being divided on the flat of block A including 50 lengthways small layers. According to the data of formation dip angle and geology knowledge, amendments are made. The structure model is finally defined combined with fault system. The fault model is shown as Fig. 1 and the grid model is shown as Fig. 2. The model layer compared with actual layer is shown as Table 1. The horizon model is shown as Fig. 3.

2.3. Analysis of sedimentary facies

After the establishment of fracture model, underground features and distribution characteristics of space are researched. Based on logging data of well points and discretization data of properties, random calculation is adapted in the module of properties computing in Petrel and sedimentary facies model is set. The sedimentary facies model is shown as Fig. 4. Facies control modeling method is being used in order to build attribute model such as permeability model, NTG model and porosity model. The permeability is shown as Fig. 5. The NTG model is shown as Fig. 6. The porosity model is shown as Fig. 7.

The simulation result shows that the main sedimentary facies is bank sand and distributary canals facies also exit. The permeability is low but the canal's is high, so as the porosity. The distribution pattern of permeability and porosity is similar to the feature of sedimentary facies. In consequence, attributive characters of the block can be well shown and a great three-dimensional model is provide for the reservoir numeral simulation.

3. The reservoir numeral simulation

The key to the reservoir numeral simulation is history matching, by using Eclipse and based on the foundation of

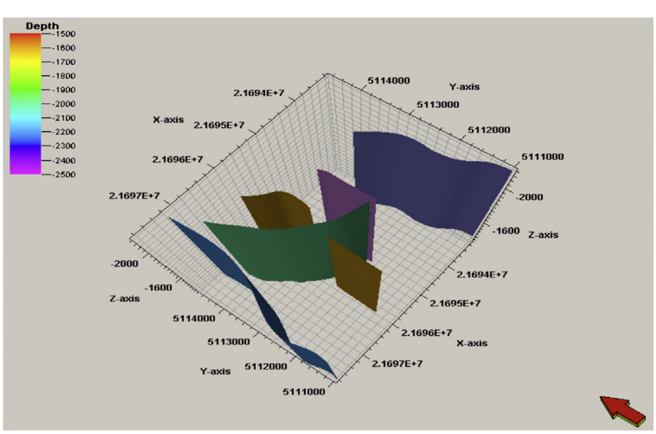


Fig. 1. The fault distribution figure.

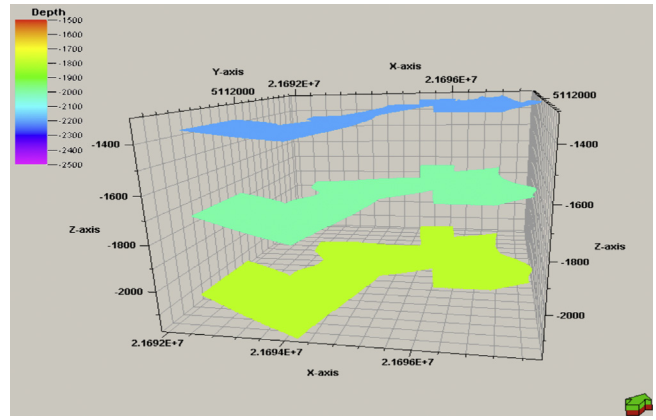


Fig. 2. Grid model of block A.

reservoir geological model, combined simulation accuracy and computing ability with real situation, the history of the model can be simulated. The concept of history simulation method is that the simulated history that has been calculated could be similar to the real history by bringing in a set of reservoir parameters. Namely, history simulation method is a way that using history dynamic to reverse calculating reservoir parameters. History simulation is a crucial part of simulation research. It is the foundation of forecasting oil field development dynamic.

3.1. The reserves fitting

The geologic model is the foundation of the numerical simulation. Conversely, the numerical simulation can verify the reliability of the geologic model by history matching. The history matching can make the model more closer to the practical geological situation of reservoir by the matches of many development items. As a result, the model can reflect distribution regularities of the residual oil precisely.

The reserves history matching is the base of the history matching. The reserves of the numerical simulation calculation is

Table 1
The layer pattition table of the model and the actual layer of block A.

Actual layer	Model layer	Actual layer	Model layer
F111	1	F311	26
F112	2	F312	27
F121	3	F321	28
F122	4	F322	29
F123	5	F331	30
F131	6	F332	31
F132	7	F341	32
F141	8	F342	33
F142	9	F351	34
F143	10	F352	35
F151	11	Y111	36
F152	12	Y112	37
F161	13	Y121	38
F162	14	Y122	39
F171	15	Y131	40
F172	16	Y132	41
F211	17	Y133	42
F212	18	Y141	43
F221	19	Y142	44
F222	20	Y151	45
F23	21	Y152	46
F241	22	Y161	47
F242	23	Y162	48
F251	24	Y171	49
F252	25	Y172	50

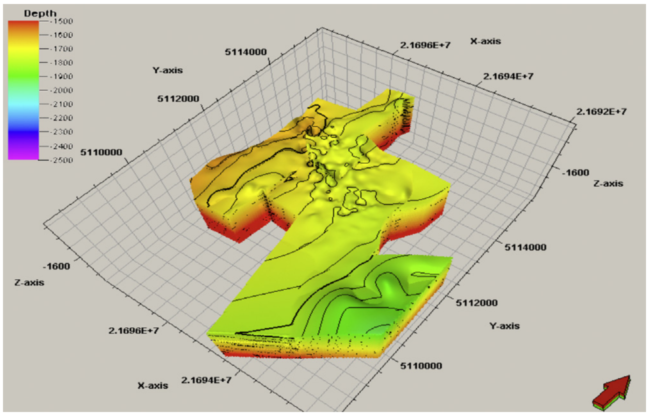


Fig. 3. Horizon model of block A.

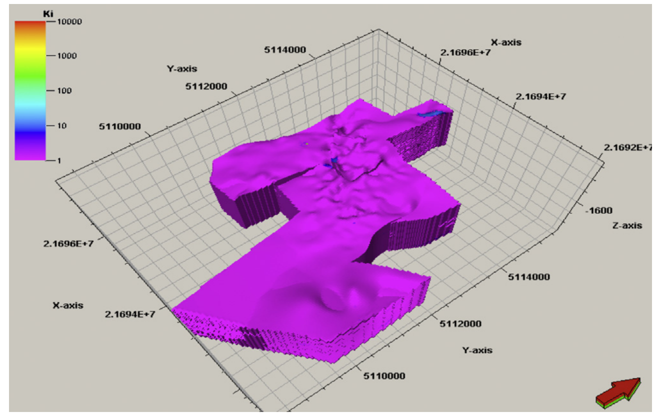


Fig. 5. Permeability model of block A.

959.18 × 10^4 t and the real reserves of the block A is 960.28 × 10^4 t. The absolute error is 1.1 × 10^4 t and the relative error is 0.11% of the history matching.

3.2. The dynamic history matching

Liquid history matching is performed at the base of reserves simulation. In general, the liquid quantity should be fixed and the production simulation is required to be fully matched. Simulation of water cut is a complicated process and it also has influences on pressure. When it is accomplished, the pressure should be simulated again. After several trails of the matching of pressure and water cut, the final model could be confirmed. Simulation of block A is conducted until 7.2013. The realistic water cut of the area is 42.22% and the simulated result is 43.18%. The relative error is 2.27%. The simulation result achieves industrial standard and the types of remaining oil can be studied next step. The liquid production rate matching curve is shown as Fig. 8. The oil production rate matching curve is shown as Fig. 9. The cumulative liquid production matching curve is shown as Fig. 10. The average water cut matching curve is shown as Fig. 11.

4. The analysis of remaining oil type

Geological and developing factors affecting the distribution of remaining oil are mainly two aspects, the geologic factors mainly include the heterogeneity of the reservoir physical properties, structure faults and sand body distribution; development factors mainly refer to the injection-production system, integrity degree of well patterns and production performance. These aspects depend on each other mutually.

Through data analysis and research for perforating, contrast of sedimentary facies and well pattern deployment, the distribution of remaining oil in this block is studied. Distribution of the remaining oil in this block is divided into four major types which include imperfect injection-production type, fault type, unidirectional water injection effect, plane interference.

(1) Remaining oil of imperfect injection-production system

Remaining oil of imperfect injection-production relationship is mainly due to the lack of water or oil wells. It can be divided into production without injection or injection without production. For example, in F122 sedimentary unit, the oil well Y20-35 and Y20-36 are lack of injection wells, so remaining oil is formed in the surrounding; in F122 sedimentary unit, the injection well Y15-46 is lack of oil wells, so remaining oil accumulates near it, as shown in Figs. 12 and 13.

(2) Remaining oil of fault blockade

Because of complicated connectivity relationship and injection/production relationship near the faults, some remaining oil is formed because of poor waterflooding. For instance, a large amount of remaining oil assembles around well Y15-43 of sedimentation unit F122 just due to the fault blockade, as shown in Fig. 14.

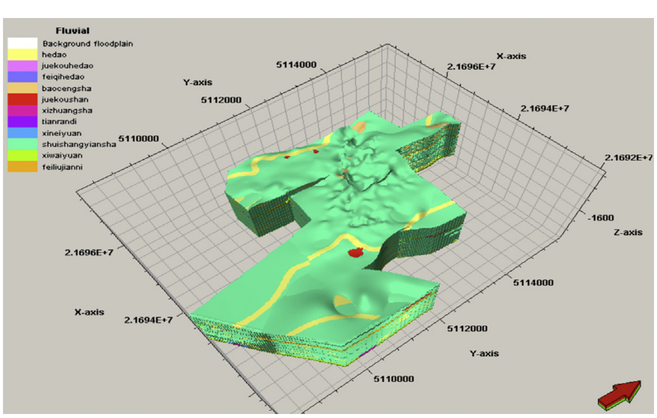


Fig. 4. Sedimentary facies model of block A.

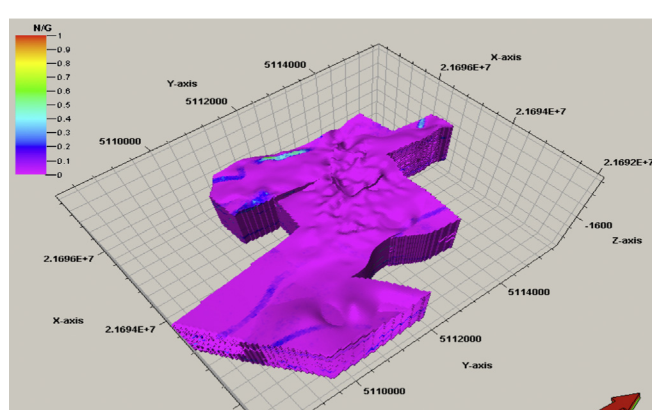


Fig. 6. Net gross model of block A.

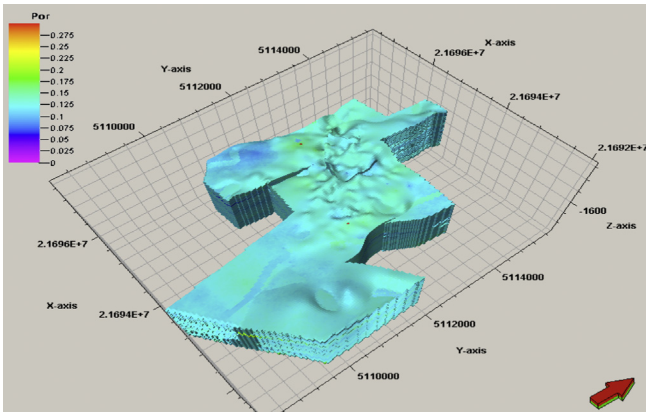


Fig. 7. Porosity model of block A.

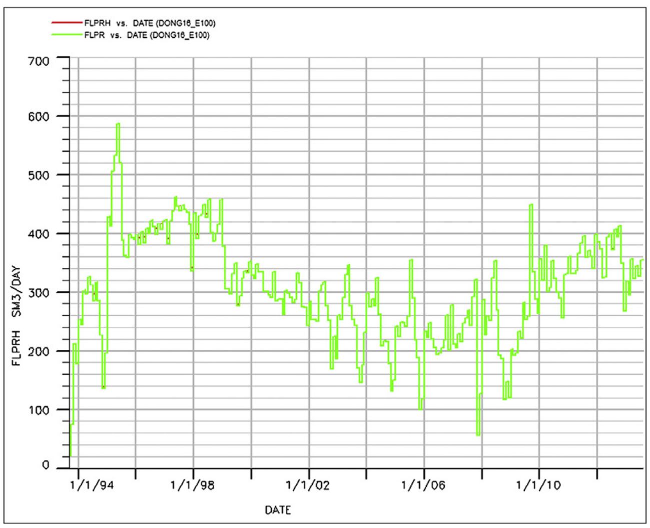


Fig. 8. Fluid production rate matched curve.

(3) Remaining oil of one-way water-injection's infection

Because of narrow river course, oil wells are just affected by water from one direction. For example, in sedimentation unit F141, well Y14-37 receives water only from well Y14-38. In

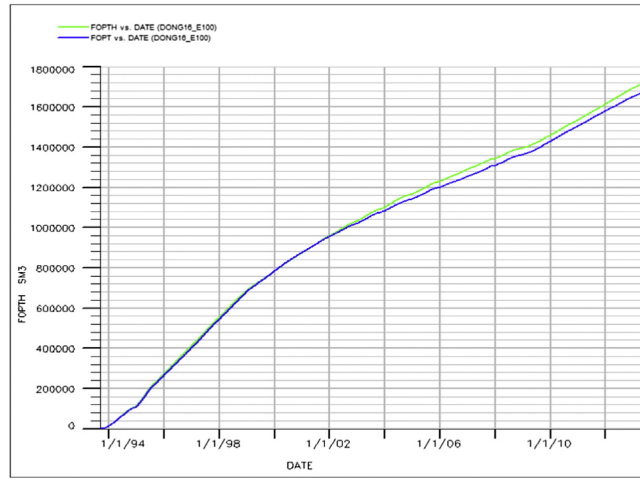


Fig. 10. Cumulative fluid production matched curve.

consequence, remaining oil is formed on the other side of it, as shown in Fig. 15.

(4) Remaining oil of plane interference

The type is affected by sedimentary micro facies. Vast discrepancy of sand body distribution in the plane causes anisotropy of permeability. Injected water will push along the direction of high permeability. The thin layers of edge and lower permeability layers get plane interference posed by the main parts of the sand body, such as well Y17-43 of sedimentation unit Y111, as shown in Fig. 16.

5. Conclusions

(1) The research of remaining oil is the foundation of the adjustment of low permeability oilfield. The research of integrated 3-D geological modeling with reservoir numerical simulation can reflect accurately the production status of the reservoir and the distribution of the residual oil.

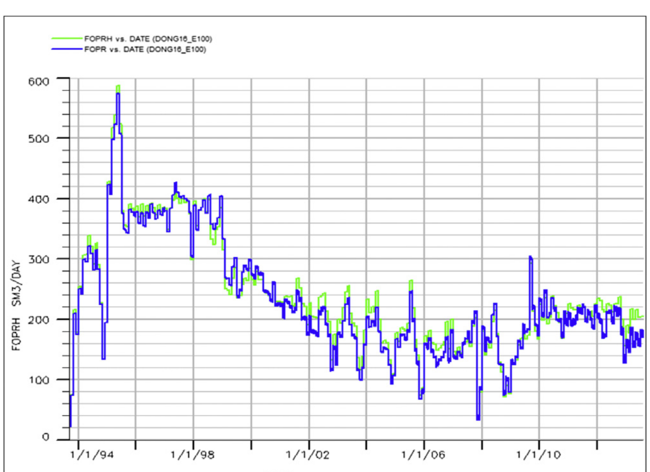


Fig. 9. Oil production rate matched curve.

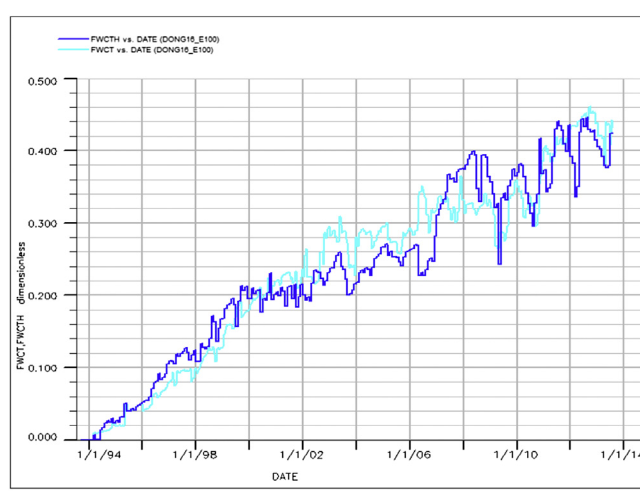
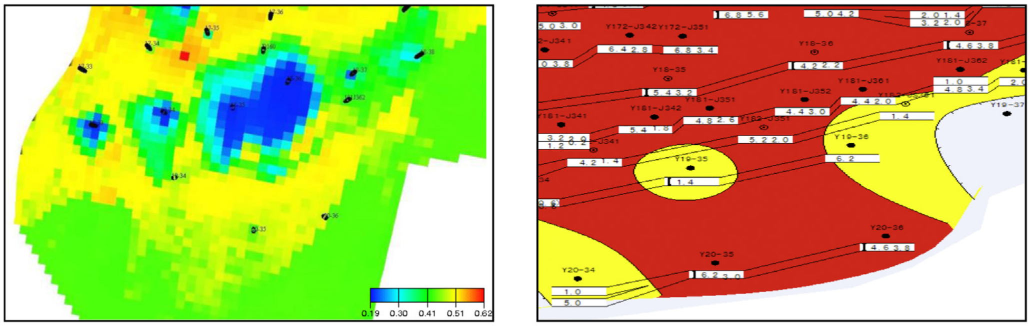
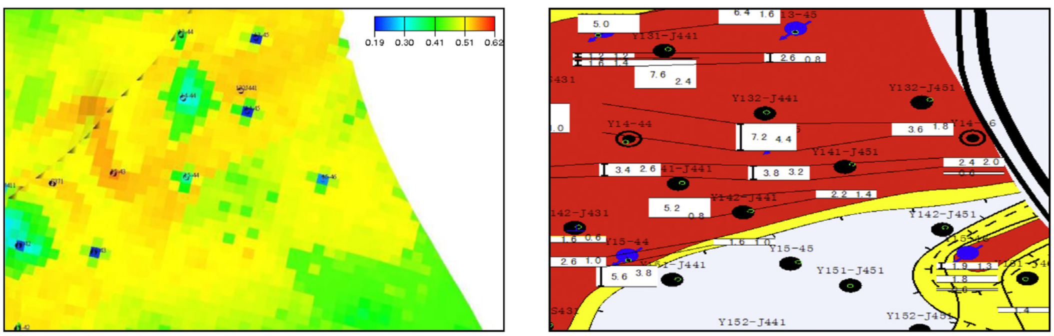


Fig. 11. Average water cut matched curve.



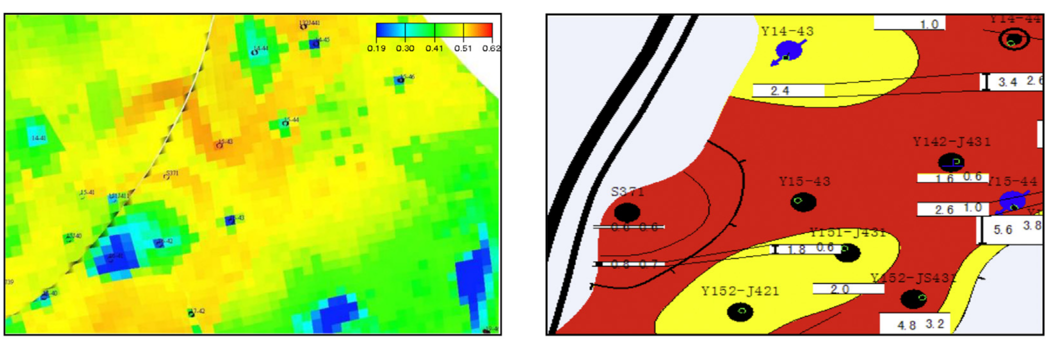
（A） The residual oil saturation of F122 sedimentary units （B） The F122 sedimentary units of sand

Fig. 12. Mining without injection type.



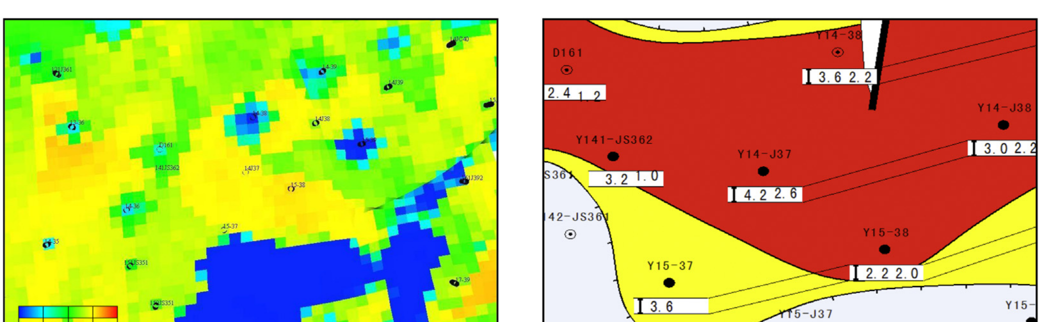
（A） The residual oil saturation of F122 sedimentary units （B） The F122 sedimentary units of sand

Fig. 13. Injection without production type.



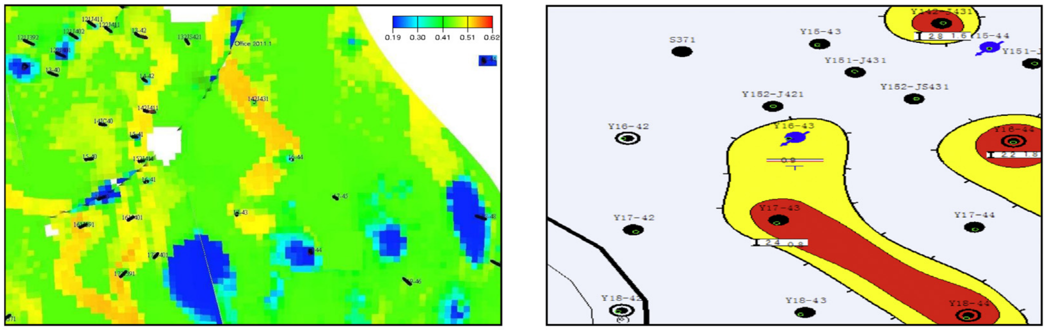
（A） The residual oil saturation of F122 sedimentary units （B） The F122 sedimentary units of sand

Fig. 14. Fault-screening remaining oil type.



（A） The residual oil saturation of F141 sedimentary units （B） The F141 sedimentary units of sand

Fig. 15. One-way water-injection's infection to remaining oil type.



（A） The residual oil saturation of Y111 sedimentary units （B） The Y111 sedimentary units of sand

Fig. 16. Plane interference remaining oil type.

(2) By using the method of the integrated 3-D geological modeling with reservoir numerical simulation, we get the conclusion that the remaining oil of the block A which is of low permeability is divided into four major types, namely imperfect injection-production type, fault type, unidirectional water injection effect, plane interference.

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